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CYCLOTRON OF MULTICHARGED IONS

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Abstract

The JSC "NIIEFA" is designing a cyclotron system intended to accelerate ions with a mass-to-charge ratio of 3-7 in the energy range of 7.5-15 MeV per nucleon. The variety of ions, the range of changes in their energy, and the intensity of the beams provide conditions for a wide range of basic and applied research, including for solving a number of technological tasks.

The cyclotron electromagnet has an H-shaped design with a pole diameter of 4 meters and a four-sector magnetic structure. In the basic mode, the dependence of the induction on the radius corresponding to the isochronous motion is realized by turning on the main coil only through the shape of the central plugs, sector side plates, and sector chamfers. For other modes of isochronous acceleration, the current in the main coil is changed and correction coils are tuned. The resonance system consists of two resonators with an operating frequency adjustable from 13 to 20 MHz. The final stage of the RF generator is installed close to the resonator and is connected to it by a conductive power input device.

The external injection system generates and separates ions with a given A/z ratio. The injection energy is chosen such that the Larmor radius is constant, which allows using an inflector of unchanged geometry for the entire list of ions.

The transportation system forms beams of accelerated ions with specified parameters and delivers them to sample irradiation devices. Computer control of the cyclotron is provided.

MAIN TECHNICAL FEATURES

A distinctive feature of heavy ions' interaction with a substance is high specific energy loss and, as a consequence, more localized dependence of the penetration depth on energy compared to light ions.

This property of heavy ions allows a broad range of applications from fundamental research in nuclear physics and sold- state physics to applied technological tasks, namely, deep layer-to-layer implantation, simulation of radiation damages of different materials, etc.

A cyclotron system producing multicharged ions is under designing in the JSC "NIIEFA". The system includes a cyclotron with an external injection system, a system to form and transport beams of accelerated ions, a sample irradiation system and utilities.

This cyclotron system is intended to generate and accelerate ions with a mass-to-charge ratio (A/z) of 3 - 7 in the energy range of 7.5-15 MeV per nucleon as well as to use this set of ions in practical applications.

Table 1 presents the calculation results of boundary accelerating modes of C, O, Ne, Si, Ar, Fe, Kr, Ag, Xe and Bi ions. For light ions, higher energies are possible.

Table 1: Boundary Modes Of Ions' Acceleration

Element	Charge	Induction in the center of the magnet, T	Energy, MeV per nucleon
Bi_{209}	35	1.29	7.28
	43	1.6	16.94
Xe_{136}	23	1.29	7.43
	28	1.56	16.12
Ag_{107}	18	1.29	7.35
	21	1.6	15.41
Kr_{84}	14	1.29	7.21
	18	1.5	16.5
Fe_{56}	9	1.41	7.53
	11	1.6	15.44
Ar_{40}	6	1.46	7.5
	10	1.29	16.2
Si_{28}	4	1.5	7.18
	6	1.49	15.93
	9	1.42	32.1
Ne_{20}	3	1.43	7.19
	4	1.56	15.22
	6	1.43	27.9
O_{18}	3	1.33	7.11
	4	1.46	15.44
O_{16}	3	1.29	9
	3	1.6	13
	5	1.42	32.1
C_{12}	2	1.29	7.21
	3	1.29	16.23
	4	1.42	34.4

The variety of ions, range of their energy and intensity variation allow us to adjust a so-called coefficient of the linear energy transfer over a broad range, which is especially important for applied researches.

ELECTROMAGNET

The iron core of the electromagnet is of an H-shaped design and of a four-sector magnetic structure. The pole diameter equals 4m. The magnet is equipped with the main coils and a set of additional radial and azimuthal coils.The induction in the center of the magnet varies in the limits of 1.29-1.6T for different types of ions. The mode with the

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1.42 T induction in the center of the magnet was chosen as the basic mode.

In the basic mode, the induction dependence on the radius corresponding to the isochronous motion is realized by turning on the main coils only through the shape of the central plugs, sector side plates, and sector chamfers. For other modes of isochronous acceleration, the current in the main coils is changed and correction coils are tuned.The beam is extracted from a fixed final radius of 1800 mm using a deflector and magnet channel.

The model of the magnet is shown in Fig. 1 and its main parameters are given in Table 2.

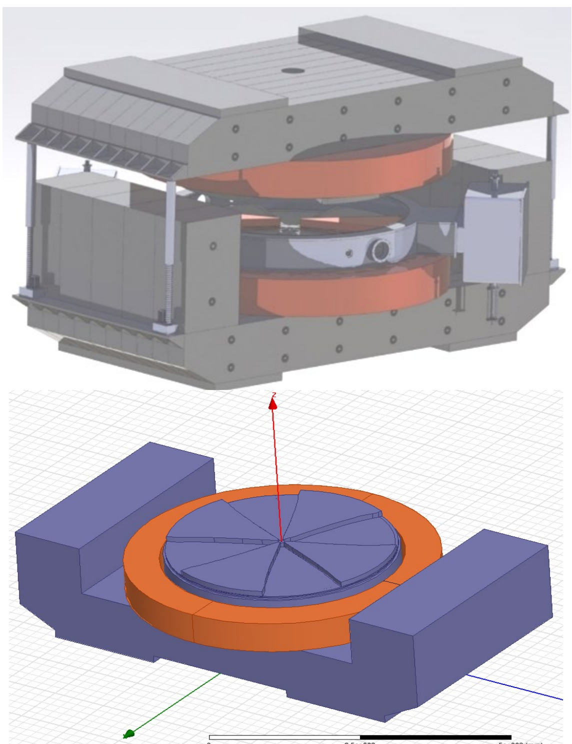

Figure 1: The electromagnet model.

Table 2: Parameters of the Electromagnet

Iron core sizes, mm	8100x4000x4300
Pole diameter, mm	4000
Number of sectors (per pole)	4
Lifting height of the upper movable half-yoke, mm	1000
Induction in the center of the magnet, T	1,29 – 1.6
Final acceleration radius, mm	1800
Sector angular length, degrees	51
Air gaps, valley/hill, mm	370/ 80
Consumed power, kW, no more than	262
Magnet mass (Fe/Cu), t	870/72
Number of radial coils Number of azimuthal coils Consumed power, kW, no more than	11×2 4×4 20

More detailed information is given in a poster report.

The vacuum chamber of the electromagnet consists of a titanium body and two covers, which are pole pieces of the iron core. Free access to the in-chamber equipment is provided by lifting up the upper movable half-yoke of the magnet.

RESONANCE SYSTEM

The resonance system consists of two mirror- symmetrical resonators galvanically coupled near the electromagnet axis. Each resonator is a quarter-wave coaxial line with conductors of variable cross-section. The frequency is controlled by changing the wave resistance of a part of the line near to the shorting flange using single-section panels.

The layout of the resonance system is shown in Fig. 2. The vertical section of the resonator with panels´ drives is given in Fig. 3.

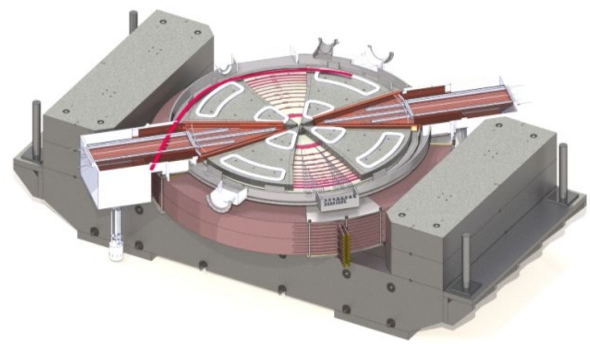

Figure 2: Layout of the resonance system.

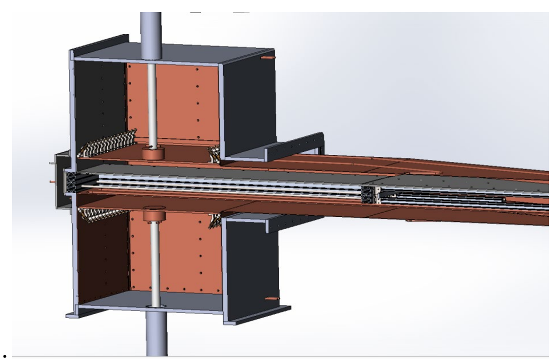

Figure 3: Resonator. Vertical section.

The resonance system includes two AFT trimmers and an RF-probe, which design is similar to that of corresponding units of cyclotrons produced by the JSC "NIIEFA". The design power of active losses in the resonance system at the highest frequency of the range is approximately 40 kW and at the lowest frequency it is 60 kW.

RF-POWER SUPPLY SYSTEM

The RF power supply system operates in the frequency range of 13 – 20 MHz. Structurally, the equipment of the system is divided into 3 units, namely, the cabinet housing the main equipment, the amplifier final stage and the high-voltage power supply. The final stage of the amplifier developed on the basis of GU - 66 generator triode is located in the direct vicinity to the resonance system. RF – power is 60 kW.

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In the light of a significant change in characteristics of the resonance system in the frequency range, the conductive power input device is used. In this version, the resonance system simultaneously functions as the final stage anode loop.

EXTERNAL INJECTION SYSTEM

The external injection system is located in the vault under the cyclotron and consists of vertical and horizontal sections. The horizontal section includes ion sources, switching magnet, devices for beam preliminary forming, diagnostics and vacuum pumping means. Two ECR sources and two electron-beam sources will be manufactured and tested, three of which will be applied in the external injection system. A 90° analyzing magnet providing separation of ions of necessary charge is installed between these two sections of the external injection system. The vertical section is equipped with solenoids, correcting magnets, diagnostics, vacuum pumping devices and a spiral inflector.

The injection energy is chosen such that the Larmor radius is constant (30.4 mm), which allows using an inflector of unchanged geometry for the entire list of ions.

BEAM TRANSPORT SYSTEM

In this project, a modular beam transport system is considered, which delivers a beam of ions to separately located target rooms (any in number). Switching and correcting magnets, quadrupole lens (shown in Figs. 4 and 5), diagnostic unit with the Faraday cup and the beam profile sensor are used as standard modules.

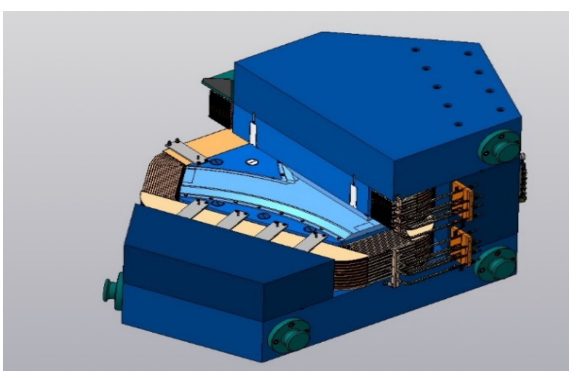

Figure 4: Switching magnet.

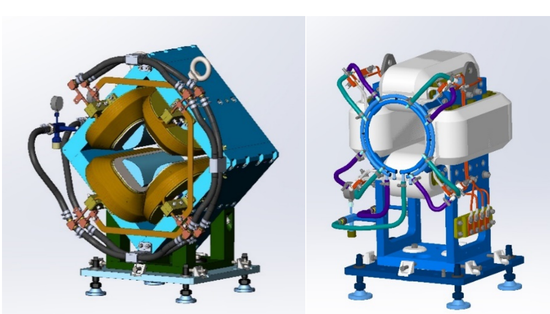

Figure 5: Quadrupole lens (left) and correcting magnet (right).

In addition, the system can include a set of collimators and diaphragms, which form a preset irradiation field, and irradiation chambers. The irradiation chambers are equipped with a special equipment for positioning and fixing of samples to be irradiated, monitoring and control of irradiation conditions, diagnostics of low-intensity ion beams.

UTILITIES

The power supply and water cooling systems are traditional for cyclotrons designed and produced in the JSC «NIIEFA».

The vacuum system must meet special requirements to minimize the intensity loss of multicharged ions. The operating pressure not more than 10^{-7} torr should be maintained in all vacuum volumes of the external injection system, cyclotron and beamlines.

To strengthen the reliability of the system, it is divided into 3 sub-systems, namely, the vacuum system of the external injection system, the vacuum system of the cyclotron and the vacuum system of beamlines. All these sub-systems can operate autonomously.

High-vacuum pumping in the external injection system is performed with eight turbomolecular pumps and five cryogenic pumps. In the vacuum chamber of the cyclotron, two cryogenic pumps are used with a pumping rate of 6500 l/s for hydrogen and a turbomolecular pump. In beamlines (with three irradiation chambers), operate eight turbomolecular pumps and six cryogenic pumps.

Possible isolation of separate vacuum volumes (ion sources, the external injection system, irradiation chambers, and some sections of beamlines) is provided to perform routine and preventive maintenance of the equipment located inside these volumes.

The cyclotron system is completely automated. An operator performs turn on/off of the cyclotron system and choice of an operating mode.

The automated control system provides a necessary consequence of turn on/off operations of the equipment, monitoring of the state of all the systems; the information obtained is visualized on screens of monitors. In an emergency situation, either separate equipment or the whole cyclotron system is automatically turned off.

CONCLUSION

This cyclotron system of multicharged ions can serve as the basis for a nuclear-physical center undertaking large-scale fundamental and applied research and solving particular tasks in the field of the radiation materials science including modification of surface layers of different articles.

Nowadays, the designing of the system is being completed and the production of the main units and systems has been started.